The Global Nuclear Energy Partnership – Challenges and Opportunities for Nonproliferation and International Security

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One of the cornerstones of the Global Nuclear Energy Partnership (GNEP) is enhanced nonproliferation and safeguards to facilitate the safe and secure global expansion of nuclear energy. To this end GNEP proposes setting up an assured fuel services framework, including spent fuel take back, to limit the spread of enrichment and reprocessing technology; and developing and implementing advanced safeguards into new fuel cycle processing and reactor facilities. The research and technology development required to achieve the GNEP vision of advanced safeguards is the mission of the Safeguards Campaign. Key areas of investigation include a) advanced instrumentation (nondestructive and destructive), b) use of process monitoring for safeguards, c) fully integrated, real time knowledge of facility operations, and d) advanced modeling and simulation tools. This paper will describe the GNEP Safeguards Campaign, the current research and technology development efforts, future vision, and the collaboration between domestic and international safeguards efforts.

Introduction

World energy demand is increasing, and with it the demand for nuclear power [1-3]. The Energy Information Administration's 2007 forecast predicts an increase of 57% in world energy consumption through 2030 [1]. Rather than decreasing as a result of plant retirement and a lack of new construction, as in prior projections, nuclear power is now projected to increase [2], as evidenced by 34 new plants under construction and an additional 86 on order or planned as of September 2007 [3].

In February 2006 as part of the Advanced Energy Initiative, the President of the United States announced the Global Nuclear Energy Partnership (GNEP), which introduced an advanced fuel cycle concept that addresses increasing energy demand, minimizes volume, heat load and radiotoxicity resulting from spent nuclear fuel, and employs both intrinsic and extrinsic measures to address proliferation issues [4]. GNEP is a voluntary international partnership where member states (numbering 16 nations as of September 2007 [5]) agree to the objectives of 1) sustainable nuclear power expansion in a way that promotes safe operations and management of wastes; 2) development, with the International Atomic Energy Agency (IAEA), of enhanced nuclear safeguards; 3) establishment of international supply frameworks to enhance reliable, cost-effective fuel services and thereby creating a viable alternative to acquisition of sensitive fuel cycle technologies (such as enrichment and reprocessing); 4) develop, demonstrate, and deploy advanced fast reactors that consume transuranic elements from recycled spent fuel; 5) promote development of advanced, grid appropriate reactors; 6) develop and demonstrate advanced technologies for recycling spent nuclear fuel; and 7) take advantage of the best available fuel cycle approaches [6].

The nonproliferation vision of the GNEP program provides for a strengthened nonproliferation regime as an integral part of the global expansion of nuclear energy by a) discouraging of the spread of enrichment and reprocessing technologies by providing reliable fuel services, b) reducing the stocks of separated civil plutonium, c) incorporation of safeguards and nonproliferation goals into the design of fuel cycle facilities, and d) development of advanced technologies to support enhanced safeguards and nonproliferation. There is no individual technological solution that will ensure the peaceful use of nuclear power, but rather the system and governance framework of nonproliferation and international security must be implemented in an integrated fashion. The challenges faced by the GNEP program also represent an opportunity to enhance the safeguardabilty of the future nuclear fuel cycle and thereby achieve increased confidence and assurance that such facilities are used only for peaceful purposes.

A significant research and technology development effort will be required to provide the foundation for achieving the GNEP vision, and as a result a GNEP safeguards campaign has been established to focus on both near term demonstration of advanced technologies as well as foundational research for the longer term. The GNEP safeguards campaign benefits from strong cooperation between the Department of Energy's (DOE) Office of Nuclear Energy (NE) and the National Nuclear Security Administration's (NNSA) Office of Nonproliferation and International Security (NA-24). Technologies developed by the campaign will specifically address domestic safeguards requirements for U.S. GNEP facilities as well as provide the technological basis for additional international safeguards.

Office of Nonproliferation and International Security

The National Nuclear Security Adminsitration's Office of Nonproliferation and International Security has a long history of providing leadership in enhancing the international nonproliferation regime and supporting the International Atomic Energy Agency (IAEA) through a combination of programs that focus on assessments, safeguards technology, export controls, infrastructure, and international engagement.

An important analysis that is underway led by NA-24 is the Nonproliferation Impact Assessment (NPIA). This is a companion document to the Programmatc Environmental Impact Statement (PEIS) for GNEP. It will compare the proliferation risks and nonproliferation benefits of the projected alternatives in the PEIS for meeting the purpose and need of the GNEP program. It will focus on how GNEP may advance longstanding nonproliferation policy objectives. It is important for U.S. policy makers to understand the nonproliferation impacts of programs that are expected to influence the international nuclear fuel cycle, particularly when nonproliferation is listed as a primary objective. Reliable fuel services is a thrust area of importance to both NNSA and the GNEP program, including developing technical and policy options for spent-fuel take-back and waste–by-products. In the area of export controls, NA-24 provides assessments for additions to the Nuclear Suppliers Group control lists and makes determinations regarding international cooperation on sensitive nuclear technologies. Two additional thrust areas benefit from collaboration and integrated support from both NE and NNSA, advanced safeguards and the promotion of safeguards by design [7,8]. They must be required for new facility types, and should be developed in cooperation with international partners and the IAEA.

Many of the same drivers for research and technology development for international safeguards are common to those of the proposed domestic U.S. GNEP enabling technology facilities (the Consolidated Fuel Treatment Center- CFTC, the Advanced Recyclying Reactor- ARR, and the Advanced Fuel Cycle Facility-AFCF). As such there is a natural synergism in research and technology development interests and the requirements to license these facilities. The licensing must meet domestic regulatory requirements along with enabling enhanced international safeguards.

Office of Nuclear Energy - GNEP Domestic Safeguards Campaign

The research and development (R&D) component of the GNEP program is housed in the Advanced Fuel Cycle Initiative (AFCI) R&D program, which is organized in thrust areas called campaigns, that are integral experimental and simulation efforts focused on developing key capabilities required for implementation of GNEP. In addition to campaigns, the R&D program includes cross cutting efforts in modeling & simulation as well as safety & regulatory. A technical integration office (TIO) coordinates and integrates the R&D efforts of the campaigns and cross cuts. Figure 1 shows the GNEP campaign structure and cross cutting areas, and their relation to the TIO. Major technology thrust areas of the program are transmutation fuels, advanced seprations technologies, systems analysis, domestic safeguards, durable waste forms, and both fast reactors and grid appropriate reactors [7].

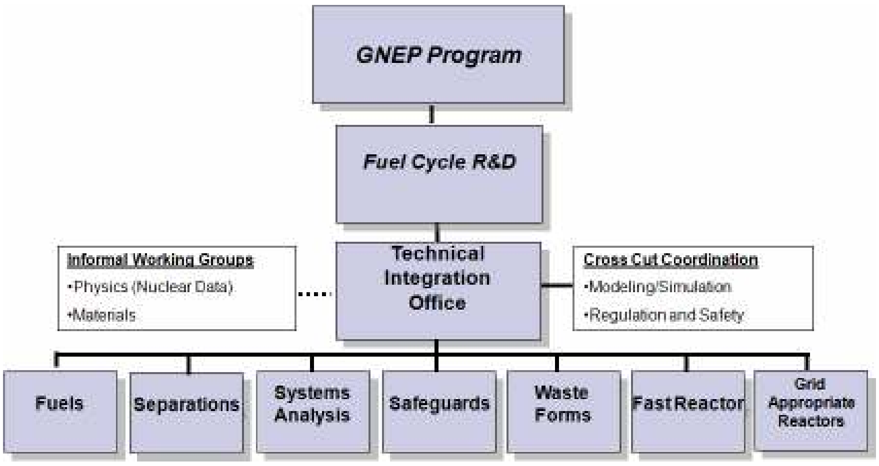

Fig. 1 GNEP R&D management structure showing technical integration office, campaign, and cross cutting areas.

The GNEP safeguards campaign has three core responsibilities: 1) support the GNEP enabling technology facilities with domestic safeguards expertise, 2) provide research and technology development in support of meeting safeguards requirements and to support advanced safeguards, and 3) interface with other campaigns and cross cutting areas. In addition, the campaign provides expertise in the area of domestic regulatory requirements and implementation, and can provide input into the review of regulations by both DOE and the NRC. International safeguards are the responsibility of NNSA's Office of Nonproliferation and International Security, with whom the campaign coordinates closely. Figure 2 presents the safeguards campaign structure and relation to the GNEP projects, regulators, and international safeguards community.

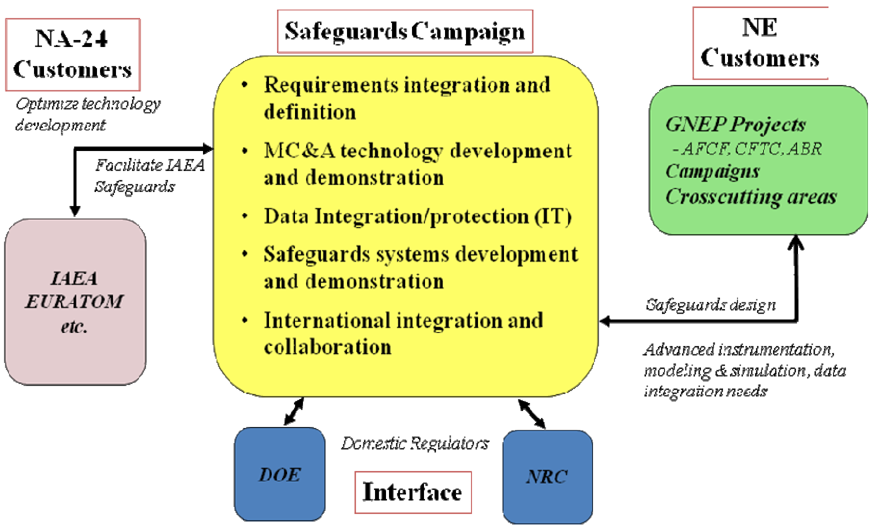

Fig. 2 GNEP safeguards campaign structure.

International and Domestic Safeguards Challenges

The global expansion of nuclear energy presents both challenges and opportunities to safeguards and nonproliferation. Challenges range from issues such as increased transportation and the need to maintain global nuclear material controls to address timeliness goals for detection of nuclear material misuse for large throughput facilities. GNEP addresses these challenges directly by providing a governance framework for the future nuclear fuel cycle that has enhanced nonproliferation and safeguards as a central tenant of the program. As such, GNEP provides the opportunity to apply new technologies and approaches to strengthen nonproliferation and safeguards.

One of the fundamental challenges to safeguards presented by the growth of civil nuclear power is offered by the large bulk handling facilities that could be built. One concern from advanced fuel cycle concepts is in the intrinsic properties of the materials that potentially would be present throughout the fuel cycle. Concern over accumulation of separated plutonium has helped drive these concepts, including GNEP, to utilize enhanced radiation as a barrier to misuse. While this is a benefit from the perspective of hindering access, these same properties can make quantitative measurement more difficult. For example, group actinide separation will result in a mixture of plutonium and minor actinides, including curium, which can in turn dominate the passive neutron emission and thereby impact standard neutron measurement approaches. Some fission products may also remain in the final fuel product, resulting in a high gamma-ray dose and making standard isotopic measurements more difficult.

Associated with intrinsic materials properties is a practical challenge to safeguards, namely the extensive use of hot cells and remote handling throughout the recycling and fuel fabrication process. This translates to equipment that must operate reliably in a much harsher environment. Not only will instrumentation need to be robust in a high radiation environment, maintenance schemes will be needed to accommodate the restricted access associated with such facilities.

Facility throughput represents another challenge. As throughput increases, the IAEA goal of 8 kg Pu for the detection of protracted and abrupt diversion represents an ever increasingly smaller fraction of the total and at some point additional measures must be taken to supplement standard nuclear material measurements. For facilities with annual throughputs on the order of 1000 ton heavy metal or more, the 8 kg Pu goal represents less than 0.1% of the total. On the other end of the spectrum, there are challenges for small throughput facilities in the case where the safeguards detection goals are based on a percentage of the active inventory, such as the case for both NRC and DOE licensed facilities (0.1% and 1% respectively).

Electrochemical processing technology is being evaluated as a recycling option and presents a special case as there is not an input accountability tank with which to establish the initial inventory as there is for aqueous processing. The potential non-homogenous nature of this process presents a particular challenge to analyses which rely on small samples. An effective safeguards approach may require even greater reliance on containment, surveillance and process monitoring than equivalent safeguards for aqueous reprocessing.

Fast reactors present a challenge to maintaining continuity of knowledge given that the core is typically in liquid metal and not accessible via traditional viewing devices (for example camera surveillance and Cerenkov radiation).

Finally, expansion of nuclear power will result in greater transportation of nuclear materials. This represents a challenge for maintenance of continuity of knowledge and for shipper-receiver differences.

Research and Technology Development Needs

Any research and technology development needed for the GNEP program would, in general, also benefit the general safeguards community - particularly international safeguards implemented by the IAEA for existing and planned fuel cycle facilities in Japan and elsewhere.

Addressing these challenges requires advances in instrumentation, systems analysis and modeling, and data integration and knowledge extraction, but also provides an opportunity to evaluate the application of safeguards in an integral sense and to develop a 'defense in depth' approach [9,10]. The opportunity also exists for including safeguards requirements in the design process, thereby maximizing their efficacy and minimizing the associated costs and impacts to the operator. This 'safeguards by design' approach is being employed for the U.S. GNEP facilities and is being developed as a potential new standard for facility design.

The research and technology development needs of GNEP fall into three broad categories:

- Advanced instrumentation – On-line and at-line, near-real time monitoring methods based on radiation and non-radiation signatures operated in active and passive mode and encompassing destructive and nondestructive analysis are needed. Process monitoring should be incorporated in a quantitative manner, and include tracking both hot (Pu and other radioactive species) and cold (non-radioactive) streams. There are nuclear and chemical data needs that support improving advanced instrumentation, evaluation of existing data and developing new data to enable new techniques. Modeling and simulation tools to support sensor design are needed, opportunities exist in new materials by design and in materials evaluation in high radiation environments.

- Safeguards by Design – Incorporating design features that facilitate safeguards and physical security requirements into the design of new facilities at the earliest possible stage is one of the best opportunities to maximize the efficacy of the safeguards system and minimize the cost and impact to the operator. Models of safeguards performance play a key role to inform decision makers regarding investment of R&D funds as well as to identify advanced approaches. Analysis of the safeguards system needs to occur at adequate levels; including facility, site, region, and global. Implementation of safeguards by design relies on both experimental and theoretical development along with lab-scale and large-scale experimental demonstration.

- Advanced control and integration – The accuracy and precision required to meet both domestic and IAEA goals using a single measurement technique are somewhere between impossible and impractical with today's technology, and as such modern facility safeguards employ a variety of tailored instruments in optimized configurations along with additional measures such as containment and surveillance, tags and seals, and integrated safeguards. In addition to developing advanced instrumentation, technology also must involve development of an integrated control system that uses all available instruments and other information through an intelligent data analyzer. The development of the advanced control system relies heavily on plant modeling and simulation, basic information management including data security, and it requires an engineering-scale facility for demonstration and optimization.

Modeling and simulation cross cuts all three of the basic thrust areas and plays an important role in sensor and advanced instrumentation development, design of the overall safeguards system for a facility, analysis of components within the safeguards system as well as the nonproliferation regime. Implementation of the advanced control system described will require plant modeling and simulation.

Putting it all together is the concept of the 'safeguards envelope' where data from traditional safeguards, process monitoring, containment and surveillance, personnel movements, etc, is folded together to form a confidence measure that a facility is operating normally. By utilizing all available data, one can envision parameterization in such a way that not only are confidence intervals developed for individual components of the system, but also for aggregates thereby accounting for correlations between disparate data [11]. In addition, experience with such a system could lead to indicators that are more predictive as opposed to reactive in nature, much like observation-based preventative maintenance in non-nuclear industries. Integrated systems models, with adequate levels of fidelity will be an important component of such analysis. The AFCF, which has as one of its missions to provide a test bed for advanced safeguards, will be particularly useful in demonstrating safeguards systems technologies and approaches.

As progress is made in the laboratory along all of these lines of research and technology development, the ability to test and demonstrate in a variety of real world settings will be crucial. Facilities at existing DOE sites need to be fully engaged in the program to provide this type of experience and benchmarking. In addition, opportunities that arise with our bilateral partners should be pursued with an eye on enabling new technologies. Finally, collaborations with universities will comprise another important aspect of advancing the state of the art and developing the next generation of professionals.

Summary

The GNEP program provides both challenges and opportunities for nonproliferation, security, and safeguards. These challenges are manageable and can be addressed through a combination of reserach and technology development. The GNEP safeguards campaign has been formed to address the research and technology development needs of the GNEP enabling technology facilities. A robust program of advanced instrumentation, safeguards analysis and evaluation, data integration and protection, and accompanying modeling and simulation has been put together to enhance safeguards effectiveness and enable the domestic GNEP facilities to meet requirements in an efficient and effective manner, and to provide a foundation for the next generation of safeguards systems.

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